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SEWAGE SLUDGE DISPOSAL IN A SANITARY LANDFILL

VOLUME I. SUMMARY AND CONCLUSIONS

OCEANSIDE, CALIFORNIA

1973

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16. Abstracts

This two volume report describes the results of work conducted during the first two years (January 1971-December 1972) of a three-year demonstration grant study of the disposal of liquid sewage sludge and septic tank pumpings into solid waste at a sanitary landfill. Pilot plant lysimeters were used to investigate the effects of sewage and septic tank sludges on solid waste temperature, decomposition, leachate settlement, insects, gases, and odors. Three large field lysimeters were monitored for leachate, temperature, gas compaction, settlement, and waste decomposition (as determined by core sampling). The full-scale disposal of sludge was monitored for runoff, leachate, equipment operating efficiency (time and motion studies), odors, vectors, blowing litter, and weather conditions (rainfall, temperature, wind, and evaporation).

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The Demonstration Grant was awarded to the City of Oceanside, California; Mr. Alton Ruden, Director of Public Works, serves as the Project Director and provided guidance necessary for the successful completion of this program. Mr. Richard Aldrich, Superintendent, Water and Sewage Department, Messrs. James Reed and John Calzada, Superintendent, and Assistant Superintendent, respectively, Waste Disposal Department, provided continuing assistance in performing the field work and collecting appropriate demonstration information.

Ralph Stone and Company, Inc. are the project consultants responsible for the detailed studies described in the report. Staff personnel include: Ralph Stone, Technical Supervisor; Richard Kahle, Project Coordinator; James Rowlands, Field Engineer, as well as many other Company professionals.

Valuable assistance in vector control and fly emergence studies was provided by the following agencies and individuals: State of California Department of Public Health, Bureau of Vector Control and Solid Waste Management - Mr. Harvey Magy, Southern California Area Representative; Dr. John Poorbaugh, Jr., Ph. D., Vector Ecologist and Mr. Don Andres, Senior Sanitary Engineer; San Diego County Department of Public Health - Mr. Daniel Bergman, Vector Ecologist. Mr. Dennis O'Leary, Executive Officer, San Diego Region, State Water Quality Control Board, cooperated in authorizing the leachate and groundwater quality tests. Many other Federal, State, County, local and private agencies and individuals have provided information to the program.

ABSTRACT

This two-volume report describes the results of two years' work (January 1971–December 1972) of a three-year demonstration study of the disposal of liquid sewage sludge and septic tank pumpings into solid waste at a sanitary landfill. Basic laboratory studies were conducted to determine the moisture absorbing capacity of typical solid waste constituents and to establish the leaching and other characteristics with various sludges. The composition and quantity of solid waste produced in the City of Oceanside were determined by first year quarterly waste samplings and waste collection vehicle weighings.

Pilot plant lysimeters were employed to investigate the effects of sewage and septic tank sludges on solid waste temperature, decomposition, leachate, settlement, insects, odor and gas characteristics. Three large field lysimeters were built at the City of Oceanside, California, municipal landfill, each holding one week's production of all municipal solid waste and sewage sludge. The field test cells were lined with a 10-mil polyethylene membrane to collect the leachate for measuring and sampling. Full scale demonstration landfill operations studies were conducted at the City landfills – initially with limited sludge disposal one day per week during Year 01, and with 100 percent sludge disposal during Years 02 and 03.

The large field lysimeters were monitored for leachate, temperature, gas, compaction, settlement and waste decomposition (as determined by core sampling). The full scale landfill disposal of sludge was monitored for runoff, leachate, equipment operating efficiency (time and motion studies), odor, vector problems, blowing litter, and weather conditions (rainfall, temperature, wind and evaporation).

Volume I consists of a 22-page summary, conclusions, and recommendations. Volume II is a 376-page description of the study on the sanitary landfill operating and design factors for disposing digested sludge and its effects on the sanitary landfill and environment. The demonstration study was supported in part by the U.S. Environmental Protection Agency under Grand Number S801582.

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SUMMARY

A. Study Background

1. Objectives and Scope. This is a report on the first two years of a three-year investigation of the economic and environmental effects of disposing liquid sewage sludge and septic tank pumpings into a sanitary landfill. The objectives of the study are to determine: 1) the capacity of solid waste to assimilate the moisture in liquid sewage sludge and septic tank pumpings; 2) the significant parameters affecting that capacity; 3) the optimum means for nuisance-free admixture of liquid sludge with solid waste in a landfill; 4) the effects of combined liquid sludge-solid waste disposal on the environment, landfill equipment, operating efficiencies, and personnel performance; 5) the effects of liquid sludge on landfill compaction and solid waste decomposition; and 6) the most economically feasible methods for dewatering, transporting, and disposing liquid sludge.

The three-year study includes laboratory evaluations of water absorption by solid waste, pilot-scale simulation of landfill conditions, full-scale field test cells for controlled landfill simulation, full-scale demonstration of liquid sewage sludge disposal in a sanitary landfill, and characterization of the sewage sludges and solid wastes generated by the City of Oceanside. Special nationwide surveys of the disposal of sewage sludge and septic tank pumpings into sanitary landfills were made by contacting responsible State public health authorities and municipal landfill managers.

2. Description of the Study Area. Oceanside is located along the Pacific Ocean coastline in northern San Diego County. In 1970, the City population was 40,494; it is projected to increase to 75,000 in 1980 and 109,000 in 2000. The climate is moderate with average temperatures (F) generally ranging from a winter low in the 50's to a summer high in the 80's, and a mean annual precipitation of about 12 inches.

All the liquid sewage sludge used in the demonstration was derived from the City of Oceanside's three sewage treatment plants, two of which are activated sludge plants, and the third a primary plant. Field tests were conducted at the City of Oceanside municipal sanitary landfill. Laboratory and pilot-scale studies were conducted at the Consultants' headquarters in Los Angeles, using Oceanside liquid sludge samples and solid waste composition. Prior to September 1972 the Oceanside landfill working face was not covered daily with soil. Operation as a sanitary landfill commenced in September 1972.

B. Sludge Disposal Practices

1. Current Disposal Problems. Federal regulations (1971) established strict limitation on disposal of sewage sludge into water bodies. This is forcing many municipalities to seek alternative methods for the processing, transport, and ultimate disposal of sludges. Sludge processing represents from 25 to 50 percent of the total

capital and operating costs of municipal sewage treatment plants. In many cases, ultimate sludge disposal requires dewatering, which accounts for a significant fraction of the total sludge disposal costs. In urban areas, the need for environmentally acceptable and economically feasible methods of sludge management is acute. The lack of suitable nearby disposal sites results in added costs for transport.

The combined disposal of digested liquid sludge with solid wastes into sanitary landfills appears to have considerable promise. It can reduce the number of waste disposal locations and eliminate costly sludge dewatering.

2. Nationwide Surveys of Sludge Disposal Into Landfills. Nationwide questionnaire surveys of State Public Health Departments and local landfill managers were completed in 1971 by Ralph Stone and Company, Inc. The objective was to assess the state-of-the-art for sewage sludge and septic tank sludge disposal into sanitary landfills, as well as to determine existing problems and authoritative opinions.

Of the 50 State Public Health Departments surveyed, 26 responded and 24 provided answers to most or all of the questions. Landfill disposal of sewage and/or septic tank sludge was permitted by State regulations in 80 percent of the responding States. The Health Departments identified the following problems associated with landfill sludge disposal: increased leachate production from liquid sludge; odor; adverse public opinion; equipment damage and compaction difficulties; nuisance and potential spread of pathogens by vectors; and difficulty in burying sludge. Four of the responding States indicated no known problems. Respondents' ratings of potential environmental hazards indicated they anticipated little to moderate hazard from landfill disposal of either type of sludge; more hazards, however, were expected from septic tank pumpings than from sewage sludge.

Of 122 responding landfill managers from 475 cities contacted, 30 percent indicated that sludge disposal was permitted at their landfills. Septic tank sludge represented less than one-half of one percent of the total sludge quantity of 537.4 million gal per year reported admixed into 24 landfills. Landfill managers also anticipated more problems and hazards with septic tank sludge than with sewage sludge landfill disposal. The pilot test drum demonstration experience indicated that septic tank sludge pumpings are more odoriferous than digested sewage sludge.

A separate nationwide survey completed by Ralph Stone for the American Society of Civil Engineers, Sanitary Engineering Division, Solid Waste Research Committee in 1962 indicated that 19 percent of reporting landfill managers permitted disposal of sewage and septic tank sludges.

C. Oceanside Solid Waste and Liquid Sewage Sludge Characteristics

1. Solid Waste Characteristics. A sample of the solid waste produced in the City of Oceanside was obtained by using statistical random number techniques to select one percent each of the single family residential, multiple unit residential, and commercial stops for special collection. Samples were taken during each of the four quarters of 1971 and hand-sorted into the nine standard categories with subcategories for absorptive materials. The average moisture content for the four quarterly samples was 25.1 percent, dry weight, and the average organic content was 61.2 percent, dry weight. Of the total waste sampled, 60.7 percent was classified as moisture-absorbing material and the remaining 39.3 percent as nonabsorbent.

Once each quarter for six consecutive collection days during 1971, all of the Oceanside Waste Disposal Department collection vehicle loads were weighed. The average daily solid waste quantity collected was about 85 tons Monday through Friday, and 25 tons on Saturday. Total estimated solid waste collected during 1971 was about 24,000 tons.

Throughout a one-week, six-day test period each month, all vehicles disposing solid waste into the Oceanside municipal landfill were counted. Of the total of 3,175 loads counted, 1,153 or 36.2 percent were from private vehicles; 1,229 or 38.7 percent were from the Oceanside Waste Disposal Department; and the remaining vehicles were from other City Departments. Demolition waste loads totalled 431 or 13.6 percent of the latter category.

2. Sewage Sludge Characteristics. The wet weight solids content of liquid digested sludge produced at each of the three City of Oceanside municipal treatment plants was: La Salina Plant, two-stage digester mixed primary and secondary sludge of 3.9 to 5.4 percent; Buena Vista Plant, one-stage digester mixed primary and secondary sludge of 2.3 to 11.2 percent; and San Luis Rey Plant, one-stage digester primary sludge of 3.3 to 8 percent. During 1971 the total quantities of liquid sludge hauled for disposal from each plant were: La Salina, 1,000,650 gal; Buena Vista, 738,700 gal; San Luis Rey, 542,000-gal--giving a total production of 2,281,350 gal.

D. Solid Wastewater Absorption Studies

1. Water Absorption Capacity of Solid Waste. Laboratory tests were made to determine the moisture-absorbing capability of particular components normally found in solid waste. Triplicate samples of solid waste were weighed, immersed in water for varying periods, then removed and weighed again. Duplicate samples were weighed, oven-dried, and reweighed to determine their dry weight. Newsprint,

miscellaneous types of paper, cardboard, grass, leaves, plant trimmings, and food scraps all reached maximum absorption (saturation) within 80 minutes after water immersion; wood blocks did not reach saturation after 200 hr, and textiles reached saturation within 10 minutes. The water absorption to saturation capacities in percent of dry weight for each waste category tested were: newsprint, 290; cardboard, 170; miscellaneous paper, 100 to 400; leaves and grass, 60 to 200; tree and shrub prunings, 10 to 100; food waste, 0 to 100; textiles, 100 to 300; and the plastics and inorganics, 0. Based on these results, the expected in-situ moisture absorption capacity of all Oceanside solid waste as received at the municipal landfill would range from 60 to 180 percent (0.6 to 1.8 lb of water per 1.0 lb of dry weight solid waste) on a dry weight solid waste basis. This would be equivalent to 48 to 145 percent (0.48 to 1.45 lb of water per 1.0 lb of solid waste) on an as-received wet weight solid waste basis.*

2. Sludge Retention Capacity of Oceanside Solid Waste. Initial tests were conducted in 13 pilot test drums to simulate the capability of solid waste of Oceanside composition to retain liquid sewage sludge. The sludge moisture saturation capacities of the test drums ranged from 0.43 to 2.1 lb of sludge per 1.0 lb of solid waste wet weight with 10 drums falling within the 1.0 to 1.7 lb range. This was equivalent to 0.57 to 2.72 lb per lb on a dry weight basis. The results indicate that the actual sludge retention capacity of Oceanside solid waste fell in the upper half of the expected range of absorption.

The ratio of liquid sludge to solid waste production in the City of Oceanside was found to be in the range of 0.50 to 0.61 lb of liquid sludge to 1.0 lb of solid waste (dry weight) which was in the low range of predicted absorption capacity of the solid waste. Field tests conducted at the Oceanside landfill during 1971 and 1972 with a liquid sludge to solid waste ratio of 0.5 to 0.61 lb to 1.0 wet weight produced no leachate, thus indicating complete absorption.

3. Water Holding Capacity of Soils. Water saturation results from the mechanism of entrainment between soil particles rather than that of absorption within particles. Water absorption tests run on typical fine sandy loam soil used as cover material at the Oceanside landfill indicated an average saturation value of 42 percent, dry weight.

E. Septic Tank Pumpings Evaluation

A literature survey, pilot tests, and a technical evaluation were completed of the feasibility of disposing septic tank pumpings into a solid waste sanitary landfill. It was found that enteric "raw sewage type" pathogens were common in septic tank pumpings. Biological organisms that have been identified include the following: bacteria--E. coli, Shigella, Salmonella, fecal streptococci, typhoid and cholera; viruses--poliomyelitis, coxsackie, infectious hepatitis, influenza, reo, and adeno; protozoa--Entamoeba histolytica; and helminthiasis and various species of tapeworm.

* Absorption capacities given are for absorption of additional moisture above the initial as-received wet weight conditions.

The common vectors for transmission of the pathogens at a landfill are: direct human contact during disposal or working the solid waste; vermin and insects that may transmit pathogens (houseflies, cockroaches and mosquitos are responsible for transmitting diseases, such as: amoebic dysentery, cholera, coxsackie, infectious hepatitis, polio, shigellosis, typhoid and paratyphoid fever, and worm infestations). Transmission also may occur by drinking polluted surface water and ground water, and by direct or indirect contamination of other animal life (sea gulls, rats, etc.).

Although the common sewage sludge digestion processes may remove or debilitate 90 to 98 percent of the pathogens, the septic tank process is relatively ineffective. Results of Oceanside core sample analyses indicate that the sanitary landfill temperatures, and gaseous and antagonistic chemical environment are apparently sufficient to destroy most enteric indicator bacteria such as fecal coliform, Pseudomonas aeruginosa and fecal streptococci. In leachate from Oceanside Cell 1, fecal coliform were 3,000 MPN nine days after filling, 300 MPN 21 days after filling and negligible 28 days after filling. The landfill temperatures (45 C to 65 C) are at the minimum required to destroy virus (50 C to 60 C). The viability and survival rates for virus in landfills are unknown.

Several studies including the aforementioned core sample bacterial analyses indicate that coliform bacteria may be seldom found in sanitary landfill soils or in landfilled solid waste below four-foot depths, and rarely below seven feet. Reports indicate that coliform that enter ground water granular stratums do not survive filtration beyond a 50-yard distance from point of entry. E. coli can be removed through filtration of as little as a 3-foot distance through a loam or other less permeable soils. Septic tank pumpings can present severe odor problems and fly vector attraction problems. The 1971 national survey of landfill practices previously cited indicated that odors and pathogenic organisms were the major operation concerns. Personnel health risks can be minimized when disposing septic tank pumpings into landfills by the following procedures: provide protective clothing and reduce exposure of landfill personnel; construct storm drainage, runoff and leachate underdrain control facilities to isolate the landfill from most water entry and collect leachate for return to sewers or other treatment; admix septic tank pumpings with solid waste in a ratio (0.5 lb pumpings per 1.0 lb solid waste dry weight) low enough to insure complete absorption; and cover at least daily with a minimum of six inches of moist, well-compacted soil to bury the wastes and control vectors.

F. Pilot-Scale Simulation of Landfill Conditions

1. Study Design. Pilot-scale tests were conducted at Ralph Stone and Company, Inc. headquarters using replicated solid waste compositions found in Oceanside, and also the representative liquid sewage sludges obtained from the three Oceanside sewage treatment plants. Domestic septic tank pumpings were obtained from Los Angeles

sources. The pilot tests were conducted in eighteen 55-gal drums to study, under controlled conditions, the behavior of various combinations of liquid sewage sludge, septic tank pumpings and solid waste compositions with respect to: absorptive capacities of solid waste for liquid sludge, septic tank pumpings and water; characteristics of leachate generated by the various admixtures; decomposition; and the environmental impact in terms of leachate, odor, fly and insect propagation, and gas generation. The quantity of wet weight solid waste placed was 100 lb in Drum 1 and 80 lb in Drums 2 through 18. The initial compaction was applied in layers in 14 drums and once en masse in four drums to simulate two methods of landfilling. Initial wet weight waste density in Drum 1 was 22 lb per cu ft, and in Drums 2 through 18 density varied from 12.4 to 22.1 lb per cu ft. Two of the drums only received water, two were dry controls, and two were subjected to forced aeration (for five minutes every hour, air was provided at 5 SCFM). With the exception of the aerated drums, each drum was sealed with airtight covers and all were exposed to the ambient environment in Los Angeles (temperatures of 45 F to 95 F).

2. Absorption Test. Liquid sewage and septic tank sludges, and water, were added to each drum over a period of 10 days until saturation was indicated by the beginning of leaching. Before saturation, the quantity of liquid added to each of 13 drums used in this test ranged from 0.5 to 2.72 lb liquid per lb of dry weight solid waste with an average of 1.74 lb per lb. Viscous digested sludge appeared to be absorbed by the solid waste more easily than water or septic tank sludge.

3. Leachate Generation. After the absorption test, water was added to 16 drums (excluding two dry controls) at a rate of one gal per working day--initially for two weeks and then revised to add 3 gal every three days, thus maintaining the gallon per day rate. This rate of water addition simulated 36 in. of cumulative rainfall over 59 days on the surface area of the test drums. The water application rate was then reduced to 3 gal per week from the 59th day to the sixth month which represented a rate of 94 in. per year. After 6 months the water application rate was further reduced to 3 gal per month, representing a rate of 22 in. per year. The total water applied to each drum (excluding two dry controls) was 90 inches. The resulting leachates were collected and the volume determined after each water application. Every two weeks leachate samples were collected for laboratory analyses (pH, conductivity, turbidity, and BOD_5) from which 50 ml was accumulated to form a composite for other detailed analyses (pH, conductivity, nitrate, chloride, total phosphate, sulfate, fluoride, organic nitrogen, iron, copper, lead, mercury, chromium and barium).

The total quantity of water added per lb dry weight of solid waste (and dry sludge solids where applicable) varied from 11 to 16 per lb through November 1972. Two moisture content determinations were made on each of the test drums one and two months after the saturation tests; three out of 15 drums showed higher moisture contents, and the remainder decreased or were unchanged. The actual water content of all but one of the 13 wetted drums decreased below its saturation level due to losses by drainage.

4. Leachate Characteristics. Analyses for BOD_5 indicated a rapid increase to peak values within 100 days of sludge/water application and a steady decrease thereafter up to 260 days. The maximum BOD_5 levels were in the range of 350 to 4,400 mg/l. The initial increase in BOD_5 may be attributed to rapid breakdown and entering into solution of complex organics in the solid waste and sludge. The subsequent decrease in BOD_5 may indicate a gradual depletion of readily soluble organics from bacterial oxidation. Drums that received mixed sewage sludges and only water had similar BOD_5 levels of around 1,000 mg/l which indicates that the organic characteristics of the solid waste were the greatest source of soluble organics.

The BOD_5 values for the two forced-aeration drums followed the same increasing value trend as the anaerobic drums, but decreased much more rapidly after peaking. This was attributed to the more rapid oxidation of organics in the presence of excess oxygen. The BOD_5 values in all drums stabilized below 60 mg/l between 300 to 500 days after filling as follows: 6 drums, 300 days; eight drums, 360 days; and one drum each at 400 and 500 days. No quantitative correlation was observed between the quantity of water added and BOD_5 stabilization; however, it was evident that intermittent wetting and drying with more than 11 lb of water per lb dry wt of solid wastes over a 300-plus day period greatly reduced the leachate pollution constituents (< 60 mg/l BOD_5).

The color of the leachates initially was black or grey in 12 drums, and yellow or tea color in three drums. Most leachates were opaque. No distinction in leachate color was detected between drums receiving only water and those with sludge. The color changed over time to a green-olive or yellow-straw color, and after 190 to 250 days it was a clear yellow or straw colog. Two grab samples of leachate from the old Oceanside landfill were grey and semi-opaque in appearance.

Leachate turbidities followed much the same increasing-then-decreasing trend of the BOD_5 values. No mathematical correlation was found between turbidity and BOD_5.

Leachate conductivity measurements also exhibited the same increasing-decreasing historical trend as BOD_5 and turbidity. Correlation between conductivity and turbidity was found to be insignificant.

A comparison of leachates from three sources - the pilot test drums, a full-scale field test cell (Cell 1) constructed at the new Oceanside landfill and filled with mixed digested sewage sludges and solid waste, and two grab samples of leachate from the old landfill indicated the following: the maximum BOD_5 value in Cell 1 (19,600 mg/l) during the first 211 days after filling was four times greater than the maximum test drum leachate BOD_5 (4,300 mg/l); the pH of the drums ranged higher (5.0 to 8.6) than both the landfill leachates (5.1 to 5.2) and the Cell 1 leachate (4.6 to 5.9); turbidities were in the same general range; conductivities in the test drums were in the same range during the first 100 days after the drums were

filled, but thereafter drum conductivities were less than one-half the conductivities in the landfill and the Cell 1 leachates; odors were similarly sour and septic up to 100 days after the drums were filled, after which the drum leachate odors became earthy and weak.

A comparison of "residual" test drum leachate occurring several weeks after water additions and "fresh" leachate occurring immediately after water addition showed that "residual" leachates had greater BOD_5, turbidity and conductivity, and lower pH values.

Analyses were made of leachate composites accumulated during 1971 and 1972 for CO_2, chlorides, phosphates, calcium, total nitrogen, nitrates, iron, copper, lead, zinc, magnesium, chromium, manganese, fluorides, barium, sulfates, conductivity, pH, and turbidity. The results showed no trends that were attributable to the type of sludge applied to each drum. Concentrations of lead, chromium, copper and manganese were negligible. Concentrations of zinc increased in 1972 over 1971, while the concentration of magnesium decreased.

5. Gas Generation. Gas samples taken from each drum every two to four weeks were analyzed for CO_2, O_2, N_2, and CH_4. Due to the introduction of excess air into the space in each drum above the level occupied by the sludge/waste admixture, the early results were inconclusive. The two forced-aeration drums contained only air, except on two occasions when the blower was inoperable and methane was detected. Some aerobic decomposition occurred in all the drums which was indicated by the presence of O_2 and generally low concentrations of CH_4 in all drums. This resulted from air entrapment in a void space between the drum covers in 1971, which was only partially corrected by adding polyethylene seal covers in 1972.

6. Compaction and Settlement. Compaction was made every two weeks by dropping a 200-lb weight twice from a height of 1 ft above the waste surface in each drum. All of the drums indicated an initial rapid settlement during the first 20 to 50 days after filling, with the exception of the high-density Drum 1. Settlements ranged from 40 to 65 percent of initial volume in all drums after 200 days except Drum 1 (30 percent in 200 days and 40 percent at 300 days), and Drum 12 (80 percent). Drum 1 was initially 32.5 percent greater in density than the other drums which probably accounted for its slower settlement. No significant differences in settlement rate were observed for the two aeration drums, while the two dry control drums tended to settle faster than several wet drums. Apparently, settlement was random exept for Drum 1 indicating that dense sludge/waste mixtures compact more slowly and to a lesser degree than less dense mixtures such as the dry controls.

7. Percolation. Percolation tests were made to determine the time-rate of leachate volume flow in the test drums. For Drum 1, the initial flow rate (0.18 gal per hr) and total leachate were significantly less than for all other drums. Comparison with Drum 9 (0.5 gal per hr) and all other drums (1.38 to 1.5 gal per hr or less) indicates the effect of high sludge/waste densities on slowing leachate flow rates. No cause was determined for the behavior of Drum 9.

8. Temperature. Temperatures measured 6 in. below the top surface of the sludge/waste mixture in Drums 6 through 18 indicated a rise during the first 90 days after filling from a range of 76 F to 84 F, to a peak range of 85 F to 92 F. The temperatures in these drums then decreased steadily thereafter to a range of 45 F to 68 F after 200 days. Temperatures in Drums 1 through 5 (filled 50 to 55 days earlier than the others) reached the same temperature ranges on the same dates, peaking 155 days after filling and reaching the lower range 250 days after filling. This indicated that temperatures in all drums followed ambient air temperature cycles rather than indicating significant thermophilic bacterial effects. This was due to a lack of insulation and the small mass to large surface area ratio of the drums, whereas in a full scale landfill there is a relatively large solid waste mass to small surface area ratio and relatively good insulation.

9. Odors. Drums filled with solid waste or water and solid waste rapidly developed odors characteristic of landfills (decaying garbage). In other drums, a septic or sulfide odor occurred in intensities relative to garbage odors varying from complete masking in two drums receiving raw primary sludge to partial masking in drums receiving mixed digested sludges. The drums with raw primary sludge emitted the strongest septic odors.

Odors from all drums were strongest during the first 90 to 110 days after initial liquid applications and became increasingly similar in type. After 130 to 170 days, odors in all but one drum changed to a moderate barnyard or compost odor, and after 150 to 205 days, odors were a negligible compost and earthy type.

Odors in the drum leachates followed essentially the same trend but were more rapidly stabilized than the odors in the drum solids.

10. Molds and Plant Growths. Mold and plant growths were observed in all but three drums from the first month (bright red in Drum 1) through the twelfth month. No significance could be attributed to growth in any drum other than an extremely large colony in Drum 1 that covered up to 30 percent of the sludge/waste surface area, compared to a maximum coverage of less than 5 percent of the surface area at one time in the other drums.

11. Insects. Flies, spiders, ants, and sow bugs were observed; of these, flies were by far the most numerous occurring in groups of up to 200 in one drum at one time. Only small flies commonly found in sewers, septic materials, or decaying organic matter were observed. Minute Black Scavengers (Scatopsidae), Fungus Gnats (Mycetophilidae), Moth or Filter Flies (Psychodidae) and a Larvae Diptera were identified. The fly population was negligible in 1972 due to the addition of the polyethylene drum seals which restricted fly travel into and from the wastes in the drums.

12. Leachate Constituents. The quantities of constituents leached from the drums through 1972 were determined in terms of lb of constituent per lb of dry weight solid waste and sludge solids in each drum. Quantities of major constituents leached from the drums varied as follows in lb per lb: BOD_5 - 1.01 to 11.1 $(10)^{-3}$; magnesium - 0.92 to 2.1 $(10)^{-4}$; iron - 3.2 to 14.2 $(10)^{-6}$; zinc - 2.7 to 11.7 $(10)^{-6}$; sulfate - 0 to 15.4 $(10)^{-4}$; phosphate - 0.57 to 11.1 $(10)^{-6}$; and nitrate - 1.2 to 285 $(10)^{-6}$. No correlation was found between the type of material in each drum and the quantities of leached constituents.

13. Comparison of Control Drums With Drums Receiving Sludge. The major differences between the wet control Drum 17 and other drums receiving sludges were: the control drum leachate pH range (6.3 to 7.2) was generally higher and narrower in range than drums receiving sludges (sewage sludge and septic tank pumpings); and gas analyses showed CO_2 and CH_4 concentrations in control drums were in the low range of drums with sludges. No differences were observed in temperature or settlement between drums with sludges and the controls. The major detectable effect of adding sludges to solid waste in the drums was the production of a more acidic leachate.

G. Controlled Field Test Cell Simulation of a Sanitary Landfill

1. Test Cell Design. During January-February 1972, three test cells were constructed at the Oceanside landfill and filled to about 13 ft of depth with solid waste and admixed sewage sludges. A 10-mil polyethylene membrane liner was placed on the bottom of each cell and covered with 8 in. of loose sandy soil. A sump with a 1-in. polyvinyl chloride (PVC) leachate drain pipe and valve was installed to collect leachate. Differential settlement markers, gas probes at mid-depth and bottom (2-in. PVC pipe), and temperature probes at the surface, mid-depth, and bottom (1-in. PVC pipe) were placed in each cell.

Each cell was filled with about one-week's production of liquid sludge and wet weight solid waste as follows: Cell 1, 45,500 gal of raw primary sludge and 473 tons of solid waste; Cell 2, 38,500 gal of mixed primary and secondary digested sludge and 394 tons of solid waste; and Cell 3, 56,000 gal of mixed primary and secondary digested sludges and 486 tons of solid waste. The total in-place combined densities of sludge solids and solid waste were 876, 902, and 923 lb per cu yd wet weight for Cells 1, 2, and 3, respectively.

2. Test Cell Study Results

a. Leachates. Leachate from Cell 1 totalled 44.8 gal almost all of which occurred during the first week after completing the cell. The leachate was negligible compared with the 45,500 gal of sludge placed in Cell 1. The raw primary sludge applied to Cell 1 was lower in total solids content (2.48 percent, wet weight) than the digested mixed sludges in Cells 2 and 3 (5.45 and 4.42 percent, wet weight, respectively).

The Cell 1 leachate analyses indicated a steadily increasing BOD_5 level from 5,450 to 19,600 mg/l; the pH increased from 4.6 to 5.9 during the first 211 days' monitoring period. Chlorides (1,160 to 1,410 mg/l), organic nitrogen (18.8 to 19.4 mg/l), TDS (16,000 to 19,000 mg/l conductivity (EC 2,750 to 6,500 μmhos/cm), and turbidity (53 to 210 JTU) appeared to have levelled between a wide band of values. Coliform bacteria decreased from greater than 3,000 MPN nine days after filling Cell 1, to less tha 3 MPN 28 days after filling. A comprehensive quarterly composite leachate analysis completed three months after cell filling indicated: no manganese or arsenic; less than 0.05 mg/l of lead, copper, and chromium; 4.7 mg/l iron; 17 mg/l boron; and 0.015 mg/l of the pesticide Aldrin. The pH was 6.1 and conductivity was 18,000 μmhos/cm. Quantities of the following constituents were also found: calcium, magnesium, sodium, potassium, chlorides, nitrates, sulfate, bicarbonate, silica, phenols, ortho phosphate, alkalinity and hardness.

During November 1972, 2.63 inches of rain fell in a one-week period. The water collected on Cell 3 and flowed through a short-circuiting depression to produce 1,403 gallons of leachate. Two samples taken 296 and 301 days after the cell was filled gave BOD_5 values of 1,050 and 1,400 mg/l, pH's of 5.1 to 5.4, turbidities of 42 and 74 JTU, chlorides of 595 and 740 mg/l, conductivities of 4,000 and 6,500 μmhos/cm and organic Kjeldahl nitrogens of 107 and 70.3 mg/l. The Cell 3 BOD_5, organic nitrogen and chlorides were much lower than found in Cell 1, thus indicating the diluted nature of the Cell 3 leachate resulting from short-circuiting of water through the solid waste.

b. Temperatures. Temperatures recorded during the first 211-day period varied from 64 to 92 F at the bottom (71 F average), 60 to 82 at mid-depth (80 F average), and 70 to 90 F near the surface (83 F average) in each cell.

c. Gas Analyses. Gas analyses taken at mid-depth and near the bottom of each cell indicated steadily increasing concentrations of methane during the first 250 days in each cell. Reported methane concentrations varied between 17 and 19 percent at the bottom of the Cells and between 10 and 18 percent at mid-depth in the Cells. Readings were taken periodically for H_2S; quantities detected in Cell 1 (5 to 750 mg/l) were significantly greater than in Cells 2 and 3 (1 to 25 mg/l). This might be expected from the raw primary sludge placed in Cell 1.

d. Settlement. Settlement in the three test cells appears to be occurring at rates of about 1.5, 2.0 and 2.9 percent per year (based on initial depth) for Cells 1, 2 and 3, respectively.

e. Core Sampling. Three core sampling studies were completed during 1972. Temperatures, moisture content and organic content were determined at two-foot depth intervals in each cell to a 12-foot depth below the surface.

Temperatures of cores from Cell 1 were higher on the first sampling, but similar to Cells 2 and 3 on subsequent sampling.

Organic and moisture contents of core samples did not show differences between the three cells. The third core sampling was completed one week after 2.63 inches of rain fell; the moisture contents in all cores were greater than for the previous core samples. The moisture and organic content of cover soils on all three cells increased after the rain.

Moisture saturation tests were run on core samples with the highest and lowest moisture contents in each cell. All but two samples had saturated values (initial plus added moisture) between 0.51 and 1.14 lb water per lb dry weight solid waste. This generally corresponds to the expected values of between 0.6 and 1.8 per lb determined in the laboratory tests.

The saturated samples noted above were used to generate leachate for BOD_5 analysis. The BOD_5 values decreased dramatically during the 58 days between the second and third core sampling (from a range of 660 to 3,070 mg/l to a range of 28 to 561 mg/l).

Core samples taken at 4-and 12-foot depths in sterile bottles on the first core sampling in July 1972 were analyzed for fecal coliform, fecal streptococci and Pseudomonas aeruginosa. The results showed some of each bacteria at the 4-foot depth and none at 12 feet. This is similar to data on coliform bacteria in soil, which reportedly do not survive below seven feet soil depth.

Odors were determined at each two-foot core sample depth interval. Odor during the first sampling was strongest in Cell 1, was relatively sweet; in Cells 2 and 3 odors were more putrid and septic. Odors on subsequent samplings were generally sour and putrid in all cells.

No differences were noted in core sample appearance, color, readability of print on paper and container labels, or biodegradeability between each of the three test cells or at different depths.

f. Comparison of Sludge Admixed Solid Waste with Normal Solid Waste. A comparison of data from the Oceanside test cells with landfills in some other Southern California locations and other field test cells was completed. The Oceanside test cell leachate pH (4.6 to 5.9) was lower than the range of values for landfills (5.6 to 7.8). Oceanside Cell 1 leachate BOD_5 (19,600) was higher than for most landfills (10,900). Temperature and gas composition followed trends at values similar to those of normal landfills. Settlement rates in the Oceanside test cells averaged two times greater than normal landfill data; this was primarily attributed to the lower original in-place density of the Oceanside test cells (623-640 lb per cu yd versus 800-1,000 lb per cu yd for wet weight solid waste only).

H. Field Demonstration of Landfill Disposal of Liquid Sludge

1. Preliminary Field Tests. Initial field demonstration tests were conducted in special test areas one day each week at the old (completed) Oceanside municipal landfill site from April to November 1971, and at the new (existing) landfill site from November 1971 to February 1972. During the first two weeks of tests in 1971, one 1,250-gal tank truckload of liquid sewage sludge was spread onto two truckloads (16,000 lb) of solid waste; during the second two weeks, 1,750 gal of sludge was applied to three truckloads of waste; after the first month, 3,500 gal of liquid sludge was spread on six truckloads of solid waste. During the first phase test period, temperatures ranged from 46 to 92 F, wind intensity was calm to moderate, and rain occurred on one day when sludge was disposed.

It was found in the initial demonstration tests that: driving a rubber-tired tank truck on compacted solid waste was impractical; sea gulls and other birds which normally foraged on the open landfill face avoided the solid waste where liquid sludge was admixed; the earthy odor of well-digested sludge was discernible for up to 30 min after application within 30 ft of the test area; and the solid waste absorbed the sludge with negligible runoff and leachate.

Extended field tests indicated that the CAT 977 and 977 K landfill dozers could work the sludge/waste admixture more easily than normal waste due to the sludge moisture improving consolidation of the sludge-wet solid waste on the landfill dozer blade. Also, less dust was generated during compaction. Greater track slippage, however, occurred when working on steep fill slopes (greater than 30 percent slope) or in areas where wet sludge was pooled.

Even application of liquid sewage sludge was critical in preventing runoff and avoiding pooling at the toe of the fill slope. Initially, liquid sludge was applied by gravity feed through a 4-in. pipe extending from the bottom of the tank truck; this method proved inadequate due to the force of the concentrated discharge stream undermining the waste and running off along the bottom of the fill surface. Solid waste dikes were built on and at the bottom of the fill working face to minimize sludge drainage. If the liquid sludge was allowed to soak into the waste for one or more hours, the dozer traction improved and the drier sludge/waste admixture was then more easily worked with minimum unusual slippage of the dozer.

During the initial 9-month preliminary test period, observations were made of odor, blowing litter, animals, and flies. On 12 of 30 weekly test days, no new significant odors were detected; on five days, earthy sewage odors existed; and on 13 days, normal landfill odors prevailed. Blowing litter was reported on only one day indicating that the applied liquid sludge reduced litter. Sea gulls, the most abundant wildlife observed at the landfill, avoided the sludge-covered wastes. Flies from normal solid wastes were observed foraging on damp sludge-covered wastes. Some sludge runoff occurred on six days, and poor sludge/waste admixing was noted on two days.

2. Full-Scale Landfill Disposal of Liquid Sewage Sludge.

a. Landfill Operations. A full-scale demonstration wherein all liquid sewage sludge produced in the City of Oceanside was disposed into the solid waste at the landfill was initiated in February 1972.

Minor runoff at the toe of the working face was observed due to partially effective sludge admixing techniques. The then-existing liquid sludge disposal schedule of two days per six-day landfill work week overloaded the solid waste, creating excessive runoff. Revising the sludge admixture schedule to five days per week reduced but did not fully eliminate minor runoff. Solid waste dikes to contain the sludge at the toe of the working face proved unsatisfactory due to dozer problems in working the pooled sludge/waste admixture. The slope of the working face was reduced from 45 degrees to 30 degrees, but the sludge tended to flow in rivulets down through channels on the fill slope. Use of a flat test spreading area made it difficult to admix the sludge evenly by gravity drainage unless the tank trucks were driven over the flat waste area. As an alternative, the cover soil was scarified on the flat, filled-landfill lift area, and sludge was discharged into the area. When the old waste fill was excavated and exposed to allow sludge admixture, severe landfill odors escaped. The surface was, therefore, quickly recovered with soil.

Alternative improved methods were investigated for spreading liquid sludge from the tank truck; they included an eight-foot movable boom suspending a four-inch diameter eight-foot long flexible hose, and a double-splash plate spreader. The boom and hose assembly was satisfactory; however, it required the truck driver to manually manipulate the boom to spread evenly. The moving boom was found to cause a driving problem. This was changed to the presently used splash-plates which mechanically cover a 12-foot wide by 6-foot half-circle twice during the spreading procedures.

The sludge truck landfill unloading time was moved up to a later hour so that there would be far more compacted solid waste present, and the landfill working face was reduced to a 30-ft width, 70-to 80-ft length, and 20-ft depth. The sludge runoff was then negligible or minimal. Other more costly methods of evenly admixing sludge to the working face by pumping or mechanical mixing with solid waste were not tested.

Observations of sludge disposal during rainfall periods indicated that if the solid waste is saturated with rainwater the sludge will become diluted by the water and some additional runoff will result. The absorbed rain also reduces the equivalent amount of liquid sludge that can be admixed or retained by the solid waste; however, during rainy periods, liquid sludge was satisfactorily disposed into the wet solid waste at the reduced rates in the Oceanside site.

b. General Observations. During a two-month period, one landfill dozer operator reported strong noxious odors from the solid waste/sewage sludge admixed fill. Field investigations and gas sampling, however, did not confirm the report. It was concluded that the dozer operator was exposed to a psychologically unpleasant environment while eating his lunch on the fill area. The fill operator now leaves the site for lunch and has continued to work without further complaint.

During warm September weather a complaint about landfill odors was received from the adjacent elementary school cafeteria. Landfill operations were discontinued in the canyon area within immediate proximity to the cafeteria. They will not be initiated in that area while school is in session. Septic, partially digested or raw sewage sludges may be disposed and cause odor, unless immediately covered with soil.

Blowing litter in the landfill was greatly reduced when liquid sludge was admixed.

Observations of sea gulls showed that they initially avoided solid waste admixed with digested liquid sludge. After seven months of full scale sludge disposal, the sea gulls lost their aversion and started foraging in areas with sludge.

Fly emergence studies were performed with sludge admixed solid waste and non-sludge solid waste test areas monthly beginning in August 1972. No difference in the two areas' emergence was discernible during the first test since large numbers of flies were encountered. No flies emerged during later tests. It was observed that flies foraged and larvae moved to dry areas in the sludge-admixed solid waste.

Accident and injury records for the landfill operations showed no injuries that were attributable to liquid sludge disposal.

A review of studies on pathogenic organisms in solid waste indicated fecal coliform and fecal streptococci bacteria may be present in large quantities. No illness has been reported by concerned school authorities, residents or landfill personnel that could be attributed to pathogens or vectors from the solid waste or sewage sludge.

3. Landfill Core Sampling. Core sampling was done by drilling bore holes in three types of landfill areas: (1) freshly placed sludge/waste up to 2 weeks old; (2) sludge/waste placed about the same time as the test cells; and (3) solid waste without sludge placed about the same time as the test cells.

Temperatures in fresh sludge/waste core samples averaged 108F and 110 F on the first two sampling periods, which was much greater than in the older sludge/waste and solid waste fill areas (79 F to 90 F). Steam was observed coming from the fresh sludge/waste bore holes. Organic contents did not differ in the three types of fill. As expected, moisture contents in the pure solid waste fill bore hole were lower than in the two sludge/solid waste bore holes.

Soil samples taken from the soil bottom below the fill in two holes, and the bottom of a lift in one hole, indicated low moisture contents well below field capacity.

No leaching was observed in the area of the bore holes or in the ground water samples from the test well at the mouth of the landfill. Laboratory moisture saturation tests conducted on core samples with the highest and lowest in-situ moisture contents indicated the amount of additional moisture absorbed to field capacity (saturation) was not related to in-situ moisture or organic content, nor depth. Lack of relationship to in-situ moisture content occurs because a sample consisting of highly absorbent materials having a high in-situ moisture content may absorb more additional moisture than a sample having material of low moisture absorbing capacity and a low in-situ moisture content.

Analyses of BOD_5 from leachates of the laboratory saturated core samples showed no differences in trends or values attributable to the different fill solid waste or liquid sludge/solid waste admixtures. The appearance of the core samples from the fill area that did not receive sludge was dry and powdery compared to wetter "pasty" agglomerated material in the sludge/admixed solid waste fill core samples. The color of the sludge/admixed waste normal core samples was usually greyish from the sludge, while the solid waste fill samples were more brownish. Readability of printed items was not affected under either fill condition. The state of biodegradation of cored materials obtained for the various sludge/non-sludge fill conditions did not noticeably differ.

Analyses of gas samples obtained from the bore holes indicated significantly higher concentrations of CO_2 and CH_4 in the sludge/solid waste fill over the non-sludge/solid waste fill.

4. Time and Motion Studies. Comparisons of time and motion data taken during landfill operations indicated that: the two dozer drivers differed significantly in the amount of non-productive time with or without sludge; the two dozers (CAT 977 and 977K) were similar in operating efficiency working solid waste; comparisons between working solid waste with and without sludge indicated no significant difference in percent of time spent working non-sludge solid waste and the normal optimum sludge ratio to solid waste (0.56 to 0.6 lb sludge per lb dry weight solid waste). Admixing a double load of sludge (1.2 per lb dry wt of solid waste) increased the percent of time spent working due to dozer slippage. It appears that if sludge is properly admixed at the noted optimum weight ratio to solid waste, the dozer efficiency is not affected.

5. Landfill Disposal Costs. The cost of full scale sludge disposal into the operating landfill during 1972 was estimated at $1.33 per ton of solid waste (wet weight) and during 1971 without sludge at $1.23 per ton. Landfill operating costs for 1972 were estimated assuming the measured 1971 solid waste quantities and are probably conservative in that more solid waste was probably disposed in 1972 due to increased urban growth. The cost of full scale sludge transport into the landfill during 1972 was $12.64 per ton of dry sludge solids disposed.

I. Preliminary Economics of Sludge Transportation

The preliminary economic analysis is based on hauling liquid sludge from the existing La Salina Plant and a new San Luis Rey Plant which is scheduled to be on-line in

1974. The new San Luis Rey Plant will be 5 miles from the existing landfill, and the La Salina Plant is 2 miles away. Assuming a sludge solids content of 3.0 to 5.5 percent wet weight for each plant, a total sludge quantity of 2,217 tons of dry sludge per year was projected for 1985.

1. Truck Haul. Three types of trucks were studied for possible truck haul of liquid sewage sludge: a modified "standard" 3,300 gallon water truck spreader; a 10,000 gallon fuel truck; and a 7,000 gallon vacuum pumper. The average costs for each truck per ton-mile haul on a dry solids basis and a 10-year useful truck life were estimated to be $3.90 for the spreader, $1.38 for the refueler, and $1.90 for the vacuum pumper. These costs apply to a weighted average load haul distance from the sewage treatment plants to the landfill of 4.63 miles with one hour per trip total for loading, travel, and unloading.

2. Pipeline Transport. Pipe head-loss and flow requirements indicated an 8-in. diameter pipe with an estimated useful life of 30 years was needed. The cost per ton-mile of dry solids was calculated to be $9.37 for the La Salina pipeline and $1.08 for the new San Luis Rey pipeline.

3. Economic Summary. The preliminary results suggest that a dual system of pipeline transport from the new San Luis Rey Plant and truck haul from the La Salina Plant could be the least costly long-term system.

CONCLUSIONS

The following tenetative conclusions are based on the results of the first two years of a three year demonstration program for conditions in Oceanside, California:

1. Laboratory tests to determine moisture absorption capacity indicated that solid waste of the composition produced in Oceanside could absorb in the range of 0.46 to 1.39 lb of liquid per 1.0 lb of solid waste as-received wet weight (0.6 to 1.8 lb per 1.0 lb, dry weight basis).

2. The City of Oceanside produces a weekly range of from 0.36 to 0.56 (0.45 average) lb of liquid digested (primary and secondary) sewage sludge for each 1.0 lb of solid waste as-received wet weight at the landfill (average 0.6 lb per 1.0 lb, dry weight basis). The 5.5 inches rainfall during the 1972 year was less than 0.1 lb rain per 1.0 lb solid waste (wet weight) as-received at the landfill. The moisture contents of a set of augered landfill samples of solid waste taken following 2.63 inches of rainfall over a 10-day period (heavy storms) indicated that the fill was well below field saturation capacity.

3. Field observations indicated that all of the digested liquid sewage sludge produced by the City of Oceanside sewage treatment plants was satisfactorily applied and absorbed in the City's landfilled solid waste without producing any observable leachate. Analyses of landfill bottom soil and intermediate lift cover soils taken from nine bore holes drilled during three field tests in 1972 indicated that no moisture entered the soil samples from either solid waste with and without admixed liquid sludge. The moisture content of the bottom and intermediate lift cover soils (average 6.8 percent dry weight) was nearly equal to the landfill surface cover soil moisture content (average 6.7 percent dry weight).

4. Analyses of solid waste samples without admixed liquid sludge and solid waste admixed with liquid sewage sludge taken from nine bore holes drilled during three field tests in 1972 indicated that solid waste without liquid sludge admixed had less than half the moisture content (average 22 percent dry weight) of solid waste with liquid sludge admixed (average 46 percent dry weight). The additional moisture (sludge admixed waste) absorbed by the core samples in laboratory tests averaged 49 percent dry weight, which was 54 percent of the total moisture saturation level. Thus, the admixture of liquid sludge and rainfall infiltration into the landfill solid waste used up only 46 percent of the total moisture absorption capacity of the solid waste core samples. Evaporation, transpiration, and gases escaping from the landfill may have reduced the in-situ landfill moisture content. The remaining 54 percent dry weight absorption capability was available for absorption of future rainfall, irrigation or drainage moisture infiltration.

5. The application of liquid digested sewage sludge by spreading onto the compacted landfill solid waste working face proved to be a better application methodology than attempts to admix solid waste into a pool of liquid sludge. The landfill dozers experienced no slippage in working the liquid sludge when it was spread and allowed to dry for a few

minutes over the surface of a working face with less than a 30 percent slope, whereas at greater working face slopes and in pooled or fresh liquid sludge the dozers experienced some slippage.

6. The addition of liquid sewage sludge to solid waste in the Oceanside landfill reduced dust and blowing litter as a result of the increased moisture content of the landfilled materials.

7. Properly engineered landfill facilities and the use of good working techniques can control liquid sludge runoff in landfills. For Oceanside, these included: admixing liquid sludge into the solid waste within an absorption ratio range of 0.46 to 1.39 lb of liquid sludge per 1.0 lb of as-received, wet weight solid waste (0.6 to 1.8 lb per 1.0 lb, dry weight basis); spreading (and drying for a few minutes) liquid sludge uniformly over a landfill working face slope of less than 30 percent to avoid short-circuiting rivulets; constructing earthen solid waste dikes at the toe of the working face to contain minor sludge and rainfall runoff; maintaining storm drain facilities to divert external rainfall runoff away from the sanitary landfill; constructing a conventional dry solid waste lift as an absorptive layer beneath the landfill prior to admixing liquid sludge; providing routine daily covering of the solid waste and sewage sludge with 6 inches of soil; and supplying proper engineering, planning and maintenance of the concerned solid waste management system and the sewage sludge treatment and disposal system.

8. A comparison of the pilot test drums, field test cells, and old landfill (without sludge) leachate analyses indicated that admixing liquid sewage sludge with solid waste produced a more acidic leachate (but not a significantly different composition) with a higher BOD_5 than that produced by solid waste alone. No major differences in temperature, CO_2 and CH_4 gas concentrations, settlement, or leachate mineral constituents have been noted between the admixed sludge/solid waste and the normal solid wastes.

9. Qualitative observations of odors resulting from admixed "well-digested" liquid sludge/solid waste at the Oceanside landfill indicated that they were similar in strength to normal solid waste landfill odors.

The pilot test drums, field test cells, and the demonstration landfill tests, with admixed well-digested primary and secondary sewage sludges, produced a mild, earthy odor until the absorbed liquid dried, after which normal landfill odors prevailed. Undigested raw sewage sludges and septic tank pumpings, however, produced moderate to strong noxious anaerobic odors which tended to intensify the landfill odors. These anaerobic odors can be controlled by immediate cover with six inches of soil or normal dry solid waste.

10. No apparent difference was observed between fly foraging in the admixed sludge/solid waste and in the dry solid waste fill. Domestic houseflies and fly larvae in solid waste were observed entrapped and escaping from the digested liquid sludge runoff. The migrating larvae (before maturing into domestic houseflies) and mature flies came into direct contact with wet sludge. Since wet sludge may contain pathogenic

organisms, the flies can pose a potential sanitation problem unless the sludge and solid waste fill is covered daily with six inches of compacted soils. Daily covering of the landfill solid waste working face with a minimum of six inches of well compacted suitable soil can also reduce fly emergence, foraging of birds, vermin and other animal vector life forms.

11. The extent of sanitary landfill leachate generation is dependent on the amount of external water introduced by surface or ground water drainage, rainfall, irrigation or other water sources. Collection and treatment of leachate from landfills both with and without admixed liquid sludge can control groundwater and surface water contamination.

12. During treatment of raw sewage sludge, the normal sludge digestion processes (aerobic and anaerobic) reportedly reduce and attenuate pathogenic organisms (bacteria, virus, etc.) by 90 to 98 percent.

13. Both Oceanside field test data and responses to a 1971 Ralph Stone and Company, Inc. nationwide survey of State Public Health Officials and local landfill operating management indicated no reported accidents, health hazards, or illness attributable to landfill sludge disposal.

No reports were found in the literature concerning adverse effects on the general public health or the health of operating personnel due to past sewage sludge disposal into landfills or spreading on land.

14. Septic tank pumpings are basically the same as raw sewage and contain similar types of pathogenic organisms (bacteria, virus, worms, etc.). The above-mentioned(conclusion 13),1971 survey reported no significant diseases occurred due to landfill disposal of septic tank pumpings.

15. Disposal of septic tank pumpings into a sanitary landfill may be feasible only under the following special controlled conditions: (1) a six-inch minimum earth cover is applied immediately after spreading the liquid; (2) proper liquid spreading techniques are used to control runoff and leachate; (3) protective clothing and face masks are employed by operating personnel; (4) the disposal site is isolated by sufficient distance or enclosures from the populated areas to positively protect the public health from vectors and to eliminate odors; (5) leachate collection and treatment facilities are provided.

16. Liquid sewage sludge in Oceanside could be most economically transported by pipeline for distances over 4 miles, and by tank truck for short distances (less than 3 miles).

17. The cost of full-scale truck transport, unloading, and disposal of liquid sewage sludge into the Oceanside landfill during 1972 was $12.64 per ton of dry sludge solids; this was economically competitive with alternative liquid digested sludge processing

and disposal methods.

18. The cost of solid waste landfill disposal operations during 1972 with full-scale disposal of liquid sewage sludge at $1.33 per ton of solid waste as-received (wet weight) was not significantly different from the cost in 1971 of $1.23 per ton of solid waste as-received (wet weight) without sludge. However, additional engineering, personnel training, operation supervision and earth cover requirements are needed when disposing sewage sludges into a solid waste sanitary landfill and, hence, an increase in long term operating costs should be anticipated. The cost effectiveness of combined (multi-purpose) disposal of both solid waste and sewage sludges appears to be improved over the duplication of disposal in separate sanitary landfill and sludge disposal works.

RECOMMENDATIONS

1. An assessment of pathogenic organisms such as virus and bacteria in leachate from landfilled liquid sewage sludge admixed with solid waste should be conducted to evaluate public health hazards and possible surface and groundwater contamination.

2. The potential vector public health hazards associated with disposal of digested liquid sewage sludge into a sanitary landfill needs further evaluation to determine the incidence of vector contamination by pathogenic organisms (virus, bacteria, etc.).

3. Special studies are needed to determine the populations and the potential for survival of pathogenic organisms in solid waste, liquid digested sewage sludge, and septic tank pumpings in a sanitary landfill environment.

4. Due to the lack of significant leachate quantities from the three Oceanside test cells, a program of water application is recommended during Year 03. The proposed water application involves applying six-inches of water per week until saturation to field capacity; and then applying water at a monthly rate equivalent to Seattle, Washington rainfall (about 42 inches per year) to compensate for high evaporation losses.

5. In order to evaluate the effect of liquid sludge disposal on landfill solid waste density, landfill compaction tests on solid waste placed in test cells with and without liquid sewage sludge admixed should be conducted. The recently installed truck scale at the landfill should be used to determine the weight of solid waste used in the compaction tests.

6. Comprehensive analyses for toxic heavy metals in leachate from sludge admixed solid waste should be performed to assess the potential for surface and groundwater contamination.

7. Further wet climate and irrigation type demonstration tests are needed to determine the effectiveness of liquid sludge disposal into a sanitary landfill under these latter conditions.

8. Long term landfill monitoring (as much as 20 years) is needed to determine the effects of time on in-situ liquid sludge admixed with solid waste.